# UCR INTELLISHARE
## – An Intelligent Shared Electric Vehicle Testbed at the University of California, Riverside –

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In 1992, the University of California, Riverside's College of Engineering established a Center for Environmental Research and Technology (CE-CERT). The research center's mission is to be a recognized leader in environmental education, collaborate with industry and government, create new technology, and be a major contributor in improving our understanding of the environment. There are three primary laboratories at CE-CERT dealing with: 1) emissions and fuels research; 2) environmental policy, atmospheric processes, and air quality modeling; and 3) transportation systems and vehicle technology research. This paper provides a brief background on these research laboratories. In addition, focus is placed on a particular transportation systems research program at CE-CERT: the development and operation of an intelligent shared electric vehicle testbed that operates on and around the UCR campus, called *UCR IntelliShare*. This program has been operational for nearly three years and has provided a wealth of data on various aspects of shared vehicle systems such as operational strategies, carsharing technology, user behavior, and how these type of systems can impact society as a whole. In this paper, the operation of the system is described in detail, along with a description of the latest results.

**Key Words:** Transportation systems research, Intelligent car sharing

## 1. INTRODUCTION

In 1992, the University of California-Riverside's College of Engineering established a Center for Environmental Research and Technology (CE-CERT). One of the key goals of CE-CERT is to serve as a model for partnerships among industry, government, and the academic community. CE-CERT's mission is multi-faceted:

1) to be a recognized leader in environmental education;
2) to be a collaborator with industry and government to improve the technical basis for regulations and policy;
3) to be a creative source of new technology; and
4) to be a contributor to a better understanding of the environment.

To accomplish this mission, CE-CERT has assembled a diverse team of researchers from numerous engineering disciplines, the physical sciences, and related fields. CE-CERT maintains a full-time, permanent staff of researchers (ranging from degreed principal investigators to technicians) to conduct research projects and operate our laboratories. These engineers and scientists collaborate with colleagues from all departments in the College of Engineering, other schools and colleges on campus, and other institutions around the world. They also supervise research by graduate and undergraduate students enrolled in the College of Engineering and other departments on campus. This breadth of expertise enables CE-CERT to take a "systems approach" to solving environmental problems and opens new and creative avenues for addressing some of the most difficult challenges facing society today.

Studying the relationship between transportation and air quality is CE-CERT's most prevalent research theme. Transportation accounts for more than half of air pollutants in urban areas, and it accounts for nearly one-third of all energy consumption in the United States. Although decades of research and development have cleaned up emissions from the transportation sector to a huge degree, significant questions about energy choices, emissions, and environmental effects require more research. To contribute to answers in these fields, CE-CERT has established programs in advanced vehicle and energy technologies, fuels, emissions measurement, control technologies, and atmospheric processes. Spinoffs from these core fields include research into stationary and point sources of pollution, water quality, land use, and planning.

Research at CE-CERT ranges from the basic to the highly applied. To help assure that our research is relevant to important issues, and to help protect our academic integrity, CE-CERT has established a Board of Advisors representing key constituencies in environmental technology, science, and policy. The board meets annually to review CE-CERT's programs and provide comments and recommendations on research themes and priorities. The board also provides review and guidance on research that CE-CERT funds internally through a growing endowment that supports faculty, staff, and student projects. Finally, the board provides a professional network that UCR students can use to begin building contacts and careers.

In this paper, we briefly describe CE-CERT's research program that is being carried out in three separate laboratories. This is followed by a focus on a particular transportation systems research program dealing with carsharing with electric vehicles. The operation of this system is described in detail, along with a description of the latest results and how it can potentially affect society as a whole.

## 2. CE-CERT'S RESEARCH PROGRAM

CE-CERT's program is organized into five broad research areas. The lines between these areas are deliberately thin. Because of the interdisciplinary nature of CE-CERT's research, it is possible to draw specific talents from the researchers at CE-CERT to carry out each unique project. The general research areas are:

***Advanced Vehicle/Transportation Technologies and Systems.*** This research area focuses on vehicle technologies that improve efficiency and reduce emissions. It also includes studies and demonstrations of transportation technologies and systems that can reduce congestion and enhance mobility alternatives in combination with reduced energy and pollution.

***Atmospheric Measurement and Modeling.*** This research area includes the development and application of technologies to measure specific pollutants in ambient air or emissions plumes. It also includes world-renowned expertise in the study of the atmospheric processes that convert emissions into pollutants such as ozone and fine particulate matter. Studies include the characterization of chemical pollutants emitted into the atmosphere, studies of transformation of pollutants after they are emitted, and characterization of emissions in the laboratory and ambient air.

***Emissions Measurement, Analysis, and Control.*** This broad research area encompasses capabilities in measurement of vehicle emissions in the laboratory and in the field, under controlled and "real world" operating conditions. Studies of the energy and environmental impacts of advanced emission control technologies and reformulated or alternative fuels are a major priority. Research also includes characterization of emissions from current and future vehicles to understand their environmental effects. CE-CERT researchers in this area develop new technologies, processes, and controls that can reduce emissions from stationary and point sources.

***Environmental Analysis and Policy.*** CE-CERT has significant expertise in transportation, emissions, and air-quality modeling. Researchers develop and apply analytical tools for present and future environmental quality and technology assessment. Research includes assessment of environmental regulations at the urban, regional, and global scale.

***Renewable Energy.*** Researchers in this area carry out projects to develop and study technologies for producing electricity and fuel from renewable resources. Research priorities include development of technology for diverting waste from landfills and producing high-quality, cost-competitive fuels and energy from feedstocks that now go to waste. Studies have included research into renewable hydrogen production, solar energy, bio-fuels for internal-combustion engines, and conversion of biomass to liquid fuel.

CE-CERT's headquarters and laboratory facilities are a short distance from the UCR campus, at the edge of a budding high-technology district. CE-CERT occupies almost 40,000 square feet of laboratory and office

**Fig. 1 CE-CERT's newly constructed building facilities: administrative building is on the left, laboratory building is on the right.**

space. In 2001, these facilities were consolidated into three adjacent buildings, two of which are brand-new and purpose-built as shown in Figure 1. The complex includes engine dynamometer laboratories, a state-of-the-art chassis dynamometer facility, chemistry laboratories, atmospheric chambers, specialized emissions analytical laboratories, electronic and computer laboratories, and facilities for vehicle modification and development. Rooftop and adjacent outdoor facilities are used for renewable energy research. A novel research project involving shared electric vehicles (described in Section 3) provides easy access between CE-CERT and the UCR campus, where CE-CERT researchers have full access to other specialized equipment and resources.

Additionally, CE-CERT operates research facilities at the California Speedway, about 12 miles away in Fontana. The Speedway has the second-largest parking lot in America, nearly four miles end to end, and thus provides an excellent resource for studies that involve driving under controlled conditions. The Speedway also features three tunnels that can be used for specialized emissions studies. To the east, CE-CERT operates facilities for heavy-duty vehicle testing and analysis in cooperation with College of the Desert, a short distance from Palm Springs in the Coachella Valley.

The University of California is a public trust, and one of its primary purposes is to carry out research that advances the frontiers of science and technology, contributes to education, and improves quality of life. CE-CERT's model is intended to pursue these objectives by providing a diverse and collaborative program to improve our understanding of the environment and to develop and assess technologies for assuring air quality and energy efficiency.

CE-CERT's research program is carried out within three laboratories:

1) Emissions and Fuels Research Laboratory;
2) Environmental Policy, Atmospheric Processes, and Modeling Laboratory; and
3) Transportation Systems and Vehicle Technology Research Laboratory.

Each of these labs and their current research programs are described below.

### 2.1 Emissions and fuels research laboratory

Research in this area involves the development and evaluation of advanced technologies associated with renewable energy and fuels, including solar energy and biofuel conversion. A stationary source research group focuses on processes ranging from cooking to manufacturing, and materials ranging from paints to industrial chemicals. The main objective of this group is to develop new technologies, processes, and controls that can reduce emissions while helping to keep businesses and industries competitive and healthy. Further, a state-of-the-art vehicle emissions research facility is used for measurement of regulated and non-regulated emissions from current and future technology vehicles. Research activities have focused on the measurement and characterization of gaseous and particulate emissions from vehicles for the development of improved emission inventories, evaluation of the effects of alternative fuels on vehicle emissions and reactivity, and evaluation of new emission control technology.

Some of the latest accomplishments dealing with light-duty vehicle emissions include gathering the largest database for the $NH_3$ emissions. $NH_3$ emissions are currently unregulated, but tunnel studies have shown relatively high $NH_3$; these emissions potentially play a key role in secondary particulate matter formation. Other recent work in mobile source emissions include quantifying the effect of sulfur in fuel on gaseous emissions. Methods and technology are also being developed for measuring extremely low emitting vehicles as part of a larger Study of Extremely Low Emitting Vehicles (SELEV) Program that has been recently initiated.

Another key area of research in this laboratory is measuring heavy-duty diesel vehicle emissions. To date, it has been difficult and expensive to measure emissions from heavy-duty vehicles due to the lack of measurement facilities. During the last three years, CE-CERT has developed a mobile trailer laboratory that can make laboratory-quality emission measurements of heavy-duty trucks under actual operating conditions (see Figure 2). This mobile laboratory contains a dilution tunnel, analyzers for gaseous emissions, and ports for particulate measurements. Although much of the system is custom-designed, the laboratory was designed to conform as closely as possible to the U.S. Code of Federal Regulations requirements for gaseous and particulate emissions measurement. The laboratory is designed to operate as a class 8 tractor is pulling it over the road (or on a closed track over a repeatable cycle); it is not a roadside testing laboratory. It also is used to measure emissions from heavy-duty stationary engines, such as pipeline pumps and backup generators, as they operate under actual loads.

Other research in this laboratory includes studying fuel effects and aftertreatment retrofits, measuring emissions from recreational vehicles (e.g., motorcycles, per-

**Fig. 2 CE-CERT's mobile emissions laboratory trailer. Exhaust from tractor is measured in trailer as the truck travels on the road.**

sonal watercraft), emissions from stationary sources such backup generators, and studying renewable energy. The main focus in CE-CERT's renewable energy research is on how waste and/or renewable materials can be converted into fuels, power, and heat.

### 2.2 Environmental policy, atmospheric processes, and modeling laboratory

The focus of this laboratory includes the following major programmatic foci:

***Environmental Policy Analysis*—**in this area, we examine the practical implications of air quality regulations from environmental, energy, social, and economic viewpoints. The major objectives in this area include the development of policy tools for environmental planning and the identification attributes of successful regulatory and technology policies.

***Atmospheric Processes*—**in this area, we are exploring the ways in which emissions react in the atmosphere, which determines their environmental impact. Through the use of ambient measurements, smog chamber simulation and modeling (see Figure 3), researchers are determining the atmospheric reactivity and secondary products of gaseous emissions. Analytical services provided in this area include field and laboratory chemical analysis of fuels, pollutants, and other substances.

***Air Quality Modeling*—**in this area, we perform theoretical evaluations of present and future urban and regional air quality. This includes photochemical air-shed modeling, source-receptor modeling, development of emission inventories, and improved numerical methods. This research develops analytical tools for predicting air quality and for assessing the impact of environmental regulations.

In the last few years, research accomplishments in atmospheric processes include developing the world's largest indoor reactivity chamber; improving the short distance dispersion modeling process; analyzing PM10 (particulate matter less than 10 microns) Deposition using LIDAR (Light Detection And Ranging) techniques; measuring PM10 emissions from paved roads; and studying the air contaminants inside of school buses. Research accomplishments in air quality modeling include the development of regional haze modeling center for the western United States; analysis of impacts of new technology gasoline vehicles on urban air quality; and research and development of air quality models. For environmental policy, recent accomplishments include the analysis of impacts of new technology gasoline vehicles on urban air quality; the development of an international vehicle emissions model for policy analysis; evaluating the impact of the use of back-up generators for normal power production during emergencies; evaluating the impact of distributed generation on urban and global air quality; and the development of an interdisciplinary program for environmental research.

**Fig. 3 Smog chamber experiments are conducted to determine reactivity factors for modeling ozone and particulate matter formation.**

### 2.3 Transportation systems and vehicle technology research laboratory

The Transportation Systems and Vehicle Technology Research Laboratory conducts research in a variety of areas, focusing on the system-level issues of multi-modal transportation. One of the primary goals of the group is to predict the air quality impact of transportation models. This is accomplished through the integration of state-of-the-art vehicle emission models with different transportation models, operating both at the microscale (e.g., corridors, intersections) and macroscale (e.g., large roadway networks). Within the group, there are seven specific areas of research: integrated transportation and emissions modeling; vehicle activity analysis; intelligent transportation systems; electric and hybrid-electric vehicle research; vehicle technology; vehicle guidance and control; and environmental materials, fuel cells and reformers.

Over the last several years, CE-CERT has developed a comprehensive modal emissions model (CMEM) that is capable of predicting instantaneous emissions of light-, medium-, and heavy-duty vehicles. CMEM is based on a load-based modeling methodology that uses various physical vehicle parameters and is easily integrated with a variety of traffic simulation models. Recent accomplishments include carrying out several studies analyzing the effects of roadway geometry and traffic flow on vehicle emissions. In conjunction with the modeling, CE-CERT has also carried out a major vehicle activity research program in Southern California, analyzing traffic flow, average speeds on different roadway types, and characterizing the overall vehicle fleet.

Advances have also been made in hybrid electric vehicle energy management strategies and hydrogen-fueled internal combustion engines. In the area of intelligent transportation systems, recent work includes the development of communication and management architectures with a focus on shared vehicle systems. In the next section, we describe in detail the shared vehicle systems research program at CE-CERT.

## 3. UCR INTELLISHARE

### 3.1 Shared vehicle system background

Today's surface transportation is facing significant challenges and demands. For example, in many metropolitan areas, the use of private automobiles is becoming a difficult prospect. Drivers are encountering increasingly frustrating congestion, spending more time on the road, and paying higher prices for parking. Congestion itself not only brings on a tremendous loss of productivity, but also results in higher fuel consumption and greater emissions. As an alternative to private automobiles, public transportation typically exists in the form of trains, subways, trams, and buses. These modes of transportation are quite economical in comparison to private automobiles, but they lack the private automobile's flexibility and availability. To fill this gap, *shared vehicle systems* have been proposed in recent years as an alternative transportation paradigm that still has a high degree of flexibility as the private automobile, but is a much more cost-effective, efficient transportation service. Shared vehicle systems are seen as an important innovation aimed at meeting long-term future surface transportation needs[1].

There are several different kinds of shared vehicle systems[2, 3]. The basic premise of shared vehicle systems is to move away from individual vehicle ownership exclusively; instead, a fleet of vehicles can be shared several times each day by different users to provide an additional mobility option. There are many potential advantages in shared vehicle systems, including:

1) They can improve transportation efficiency by reducing the number of private vehicles that are required to meet total travel demand; as a result, vehicles spend a lot less time sitting idle in parking lots and are used more often by several users;
2) Users can potentially save on transportation costs since vehicle expenses (e.g., payments, insurance, maintenance, etc.) are shared among all users of the system (many carsharing organizations state that significant cost savings are achieved when their corresponding private vehicle annual kilometers driven is typically less than 10,000);
3) An energy/emissions benefit comes when low-polluting (e.g., electric*) vehicles are used in the shared vehicle system; and
4) Transit ridership is increased when individuals use shared-vehicle systems either through a direct transit linkage or indirectly because they more consciously consider their tripmaking decisions due to carsharing.

The key characteristic of all shared vehicle systems is the concept of resource sharing: single vehicles are used many times each day by different users. As with any resource sharing problem, mechanisms must be in place to effectively manage the resources, as well as satisfy the users of the resources. There is an important need for integrating information and communication technologies into shared vehicle systems in order to manage resources and satisfy demand. These technologies can include communications between vehicles and the system, vehicle tracking, reservation and dispatching systems, on-board navigation and travel information, and smartcard technology.

The most popular type of shared vehicle system is the car sharing organization (CSO, see a review[3]). A CSO owns a fleet of vehicles that their users can access throughout the day. A user either reserves a vehicle in

* In fact, electric vehicles are in general a good match for shared vehicle systems, since shared vehicle trips typically have short to medium range and electric vehicles can take advantage of opportunity charging when idle at their holding locations.

advance or simply walks up to an available vehicle. The keys are typically obtained through a common lock box, and then the vehicle can be used for a period of time. At the conclusion of the trip, the vehicle is returned (typically to the original location) and the mileage and time are recorded. At the end of the month, each user is billed a small user fee plus a mileage-based charge. Another type of shared vehicle system is the station car, which is usually associated with a long-haul transportation mode, such as rail. In this case, users can access station cars at both ends of their commutes. A more generalized shared vehicle system is one in which shared vehicles are used among multiple stations or nodes to travel from one activity center to another. Such systems may be located at resorts, recreational areas, university campuses, etc. As an example, a user may arrive by rail or plane, then rent a shared vehicle to drive from the station or airport to a hotel. Later on, the user may travel from the hotel to a shopping mall or to a tourist attraction. In this way, the trips are more likely to be one-way each time in contrast to the typical roundtrips made in traditional commuter station car system or non-commute-based CSO. Because there are many more one-way trips in a multiple station scenario, the number of shared vehicles at each station can quickly become disproportionally distributed among the stations[4,5]. At different times in the day, some stations will have an excess of vehicles while other stations will have a shortage. As a result, it is sometimes necessary to relocate vehicles periodically each day so that the system operates efficiently and (most) users' demands are satisfied.

Over the last several years, there has been a proliferation of shared vehicle systems around the world. Many of these systems take on different configurations and purposes; nevertheless, they all have a common component of using vehicles in a shared-use setting. This is a rapidly growing field, spawning several conferences/workshops that allow practitioners, researchers, and enthusiasts to gather to discuss the many issues associated with shared vehicles (e.g., the First North America Car Sharing Conference held in Atlanta, Georgia in March 2001, and the Shared-Use Station Car Summit held in Irvine, California in July 2001). Recent efforts have been made to attempt to classify these different types of shared vehicle systems[2].

### 3.2 UCR IntelliShare operational overview

Extensive research and analysis has been carried out on multiple station shared vehicle systems at CE-CERT using a variety of shared vehicle system computer simulation tools[5]. The simulation analysis has shown that the shared vehicle concept is both viable and potentially economically profitable. However, there are always limitations to what can be simulated: in particular, human behavior and how people will react and use such a system. Further, detailed knowledge is needed on how to actually implement and operate highly automated shared (electric) vehicle systems. CE-CERT has designed and implemented a small-scale, automated shared electric vehicle system testbed on and near the UC Riverside campus, called UCR IntelliShare. There are several project goals; however, the three primary objectives of the UCR IntelliShare system are:

- to develop an advanced system architecture and new operating techniques for shared vehicle systems;
- using operational data from the system, to improve the fidelity of our shared vehicle system simulation models; and
- to provide the UC Riverside campus with a convenient, environmentally-friendly, and efficient transportation system.

In the UCR IntelliShare system, initially 15 (now 25) Honda EV Plus electric vehicles are available to UCR faculty, staff, and student employees at three stations set up on and near campus (see Figure 4):

1. CE-CERT, located approximately 3 miles from campus, which serves as an off-campus research laboratory for the College of Engineering;
2. The College of Engineering primary building located centrally on campus; and
3. University Village, located approximately one mile off the main campus, consisting of retail shops, movie theaters, restaurants, and several university-related offices.

To help make the UCR IntelliShare system manageable and convenient to users, the system makes use of the latest ITS technology:

- UCR IntelliShare is a keyless system. Users simply carry and utilize smartcards that allow them to access the station kiosks, the station buildings, and the vehicles themselves. Traditional keys are not used in the system.
- Each station in the UCR IntelliShare system uses a kiosk to register for trips. These kiosks consist of touchscreen displays where a user can simply swipe his or her card, push a few buttons, and begin the trip.

To manage the system, CE-CERT operators monitor the location and operational status of each vehicle

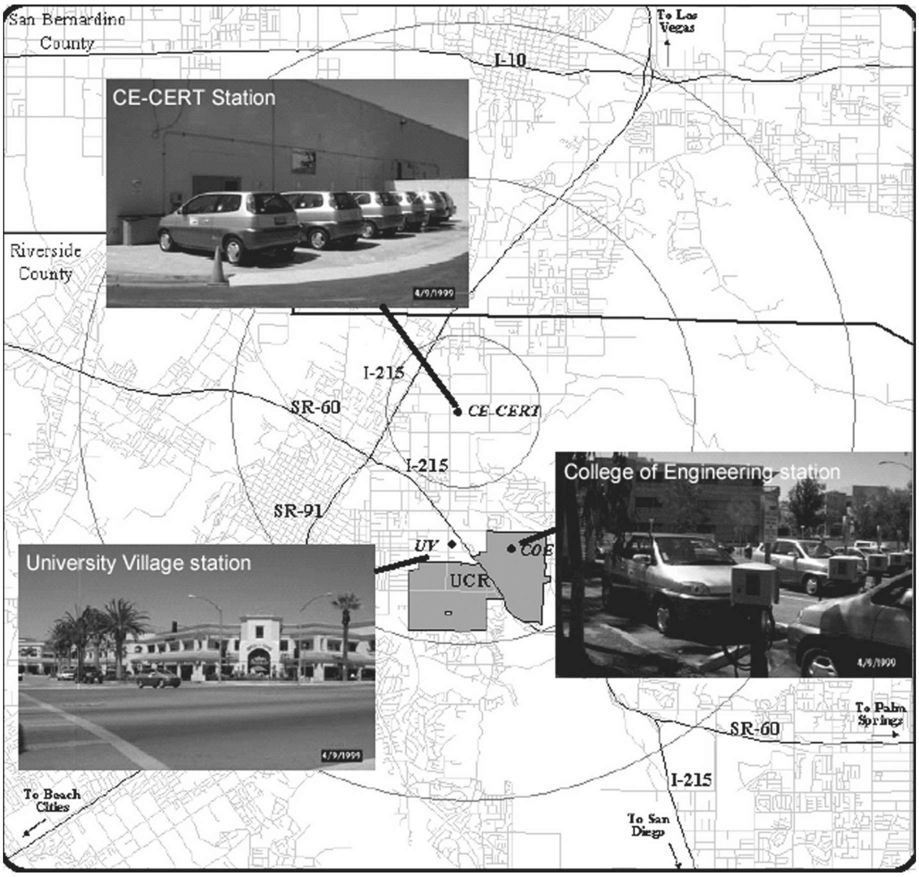


**Fig. 4 UCR IntelliShare stations**

(e.g., battery state-of-charge, odometer, etc.) using advanced vehicle monitoring technology. These data allow the system to intelligently determine the availability of vehicles for other users.

Users can quickly and easily obtain a vehicle electronically at the automated kiosks located at each station. The user may return the vehicle to any station, where the vehicle then becomes available for another user. In its current implementation, the UCR IntelliShare system does not require reservations. Instead, using the touchscreen computer and smartcard, a registered user provides information about his or her anticipated trip and is assigned a particular Honda EV Plus vehicle in the fleet. To gain access to the vehicle, the driver uses the smartcard to unlock the driver-side door and engage the ignition. Once the trip is under way, vehicle status is sent to the system management center every 30 seconds. Drivers can also send and receive messages using a small keypad located in each vehicle. For instance, if a car has a flat tire, the driver can notify the system management center. When a user arrives at a station (not necessarily the originally specified destination station), parks the car, and steps out of the vehicle, the system automatically logs the user off, locks down the vehicle, and makes the vehicle available for other users. If the user is on an errand trip, parks the vehicle, and gets out at a non-station location, the system still locks down the vehicle without removing user access. The user can return and use his smartcard again to gain access to the vehicle. Only when the vehicle is returned to a station will the user be logged off.

In the current implementation, trips up to 15 minutes in length are free of charge. A nonlinear incremental fee is charged for trips that are over 15 minutes. For example, an hour-long trip costs the user a little over $1, while a two-hour trip costs over $3. Keeping the vehicle longer than a few hours is prohibitively expensive. As an initial user base, approximately 350 staff and faculty members at UC Riverside are using the system.

The Honda EV Plus four-seat sedans are electric vehicles, using nickel-metal hydride batteries. They have a range of approximately 80 miles before they require recharging. Recharging docks are located at all three UCR IntelliShare stations. Using acquired trip and vehicle information, the system management center staff attempt to keep the (idle) vehicles more or less evenly distributed among the three locations. If necessary, vehicles are relocated to another location in the system.

The UCR IntelliShare system has been funded from a variety of sources. The primary sponsor and research partner is Honda Motor Company. Other sponsors include the University of California Digital Media Initiative Program, the City of Riverside, and the South Coast Air Quality Management District.

### 3.3 Recent results

The UCR IntelliShare system began operation in April 1999. Users were gradually brought into the system, with users from the CE-CERT research center initially using the system, followed by College of Engineering users, and then users from the university offices located near the University Village station. At the beginning of 2002, approximately 350 UCR employees are using the system. On average, approximately 110 trips are made per day, with over 47,000 trips made between 4/1999 and 2/2002. The details of each of these trips are logged in our database, providing a rich dataset for analyzing system effectiveness, user behavior, and vehicle operation. Based on this dataset, we have been able to incrementally improve the operation of the system and have the ability to conduct various "experiments" in system operation.

An enormous amount of information and knowledge can be gained regarding how users interact with this type of shared vehicle system. On an average day, each vehicle is used approximately 7 to 8 times. Approximately 45% of the trips are made from one station to another, while 55% are errand trips (e.g., the origin and destination stations are the same). Figure 5 displays the average diurnal profile of use for all user trips. This demonstrates that the users do not use the vehicles with equal frequency throughout the day. The UCR IntelliShare system use is minimal prior to 9:00 AM and steadily increases towards noon. System use then becomes maximized during the lunchtime hours and gradually diminishes towards 5 PM. After 5 PM the system use is minimal once again. We have examined changes in the diurnal pattern and have documented this[6].

Figure 6 displays the total trip length frequency. Again, 45% of the trips made by users are one-way trips between two stations and therefore are very short in length and duration. Many of the errand type trips (where the user has an intermediate destination) also are short in length and duration, although some are much longer in distance and duration. In Figure 6, it can be seen that the majority of trips are in the range of 4 to 10 kilometers with a gradual decline in frequency as the total trip length increases. Long trips are discouraged within the UCR IntelliShare system and therefore few trips occur of

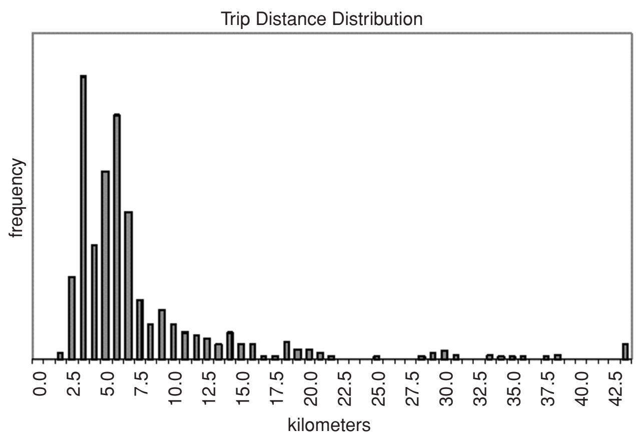


**Fig. 6 Frequency plot of trip distances (kilometers)**

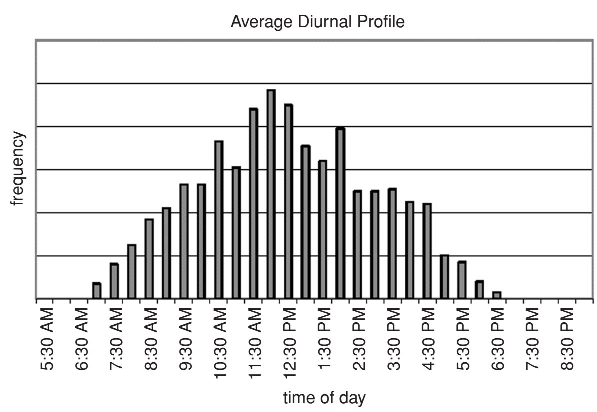


**Fig. 5 Diurnal profile of use for an average day**

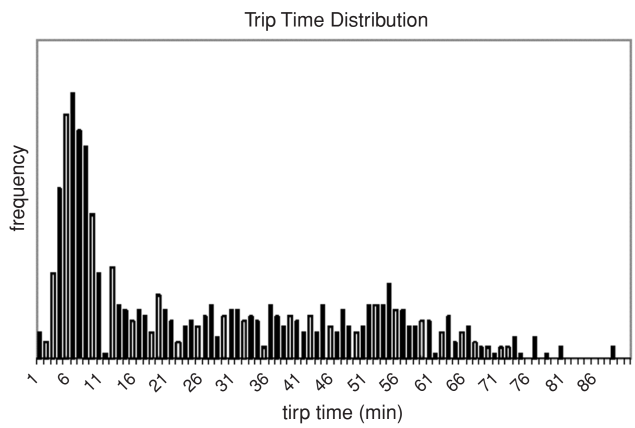


**Fig. 7 Frequency plot of trip duration (minutes)**

great distance. Similar to trip distance, Figure 7 shows the frequency of trip duration. Since users incur an increasing charge for trips greater than 15 minutes in duration, most trips are less than an hour. The average vehicle ridership of these vehicles is approximately 1.45 people per trip.

The UCR IntelliShare user-base varies greatly. Some users are undergraduate students working within the College of Engineering. Some users are faculty, while other users are university staff. This diversity suggests a wide variety of system usage by different people. Figure 8 shows the cumulative distribution of trips made by all users, at different times of the year. The cumulative distribution is ordered by users whom complete the greatest number of trips to users whom complete the least number of trips. Therefore, the quantity of users can be determined from the percentage of users remaining when 100% of the trips have been cumulated. During October of 1999 nearly 30% of the users did not utilize the system. During January and March of 2000 approximately 40% and 45% of the users did not use the system, respectively. With time, we continue to add more subscribers and the number of subscribers who do not use the system proportionally increases. In October 1999, 60% of the total trips were made by 20% of the users. In mid-2000, approximately 50% of the trips are made by only 10% of the users. As this curve gets farther and farther out, it may be necessary to start a monthly subscription fee in order to reduce the number of subscribers who do not use the system.

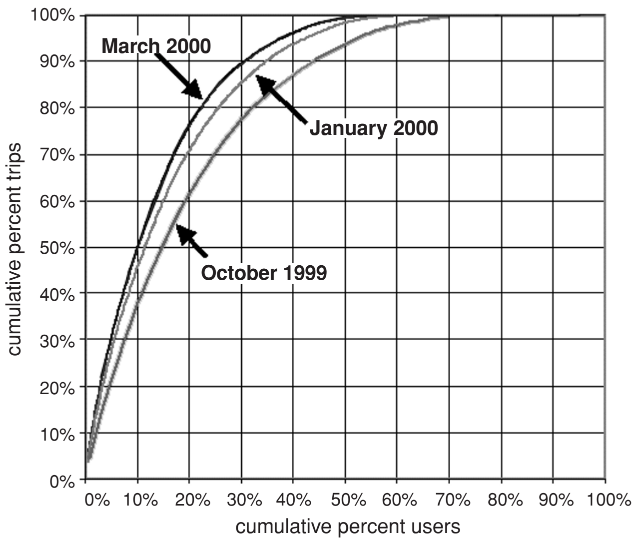


**Fig. 8 Cumulative percent of trips by cumulative percent of users**

There are several methods of determining the effectiveness of the system, including average customer wait time, number of relocations required, percent of time each vehicle is in use, and cumulative time that stations are without vehicles (for details on these measures[5, 7]). Thus far, the percent of time an average vehicle is in use is approximately 30%, far greater than that of a private automobile.

This research testbed has enabled 15 patent applications and several research papers. Shared vehicle system simulation analysis is described[5]; advanced operational strategies for shared vehicle systems are described[8]; the supporting intelligent transportation system architecture is described[9]; analysis of shared vehicle system user behavior is given[6]; an evaluation of the system efficiency is provided[7]; and a detailed description of UCR IntelliShare's wireless communication techniques is given[10].

### 3.4 Future expansion

In the past year, there have been several key conferences dedicated solely to shared vehicle systems. These conferences have allowed practitioners, researchers, and enthusiasts to gather to discuss the many issues associated with shared vehicles. One of the key findings discussed at these conferences is that in order for shared vehicle systems to best succeed, they must provide users with maximum flexibility and choice. In particular, many users will have different trip purposes, and therefore will have different vehicle needs. As a result, it is important to have a *heterogeneous* vehicle fleet in any shared vehicle system.

To date, all trip activity in the UCR IntelliShare system has been satisfied using Honda EV Plus four-seat electric sedans. As a result, UCR IntelliShare is currently expanding in two ways:

1) the number of vehicle stations on campus are increasing for better access; and
2) additional vehicle types are being introduced into the system to improve system flexibility.

Two additional stations are currently being established on the UCR campus: one station will go into place on the far south side of campus while the another will be placed closer to UCR's main administration building. Honda Motor Company has recently provided 10 additional EV Plus vehicles (for a total of 25) so that approximately 5 vehicles will be located at the 5 stations.

In addition, eleven neighborhood electric vehicles (NEVs) are planned to be added to the UCR IntelliShare system. These NEVs will improve the system by providing additional mobility in and around campus. Three types of NEVs will be incorporated: a four-seat NEV, a two-seat NEV, and a utility NEV. The overall strategy for the expansion of UCR IntelliShare is to have many on-campus trips be satisfied by the NEVs. Because the speed of NEVs is limited, they are restricted for use only on streets that have speed limits at or less than 35 mph. On the UCR campus and in the immediate surrounding area, all roads have speed limits less than 35 mph. Therefore, it is planned to have many UCR IntelliShare trips around campus be satisfied with the NEVs. Trips that require traveling significantly off campus would then be satisfied by the freeway-capable EVPlus vehicles.

## 4. CONCLUSIONS AND FUTURE WORK

In ten years time, CE-CERT has grown into a preeminent research center focusing on transportation and environmental issues. There are many on-going research projects that are having a direct impact on society. Much of the research carried out at CE-CERT is used to improve our understanding between vehicles, transportation systems, and the environment. Often the results of these research projects are used to help define policy and regulation. In the future, CE-CERT will continue to focus on vehicle emissions research, with a focus on heavy-duty diesel vehicles and extremely low-emitting vehicles. Many modeling tools will continue to be developed, ranging from specific vehicle operation to regional atmospheric processes. These modeling tools provide the basis for much of the evaluations we do. The transportation systems research laboratory will continue to evaluate current and future transportation systems, with a focus on designing environmentally friendly systems.

As one of the major transportation systems research areas at CE-CERT, shared vehicle systems will continue to be an area of concentration. The UCR IntelliShare testbed allows us to perform a variety of experiments in carsharing, allowing for the eventual implementation of clean, efficient transportation technologies that improve the environment, reduce energy consumption, and contribute to improved mobility. It is clear that shared vehicle systems will play a major role in society's future transportation systems. These systems have the potential to improve transportation efficiency (by reducing the number of vehicles required to meet travel demand), save user costs, improve the environment, and enhance transit ridership. By evaluating shared vehicle system concepts in our testbed, much can be learned prior to large scale implementations as commercial systems.

## REFERENCES

1. Britton et al. "Carsharing 2000: A hammer for sustainable development", *Journal of World Transport Policy and Practice*, The Commons — Technology, Economy, Society, Paris, France. (2000).
2. Barth, M. and S. Shaheen. "Shared-use Vehicle Systems: A Framework for Classifying Carsharing, Station Cars, and Combined Approaches", to appear, *Transportation Research Record*, Transportation Research Board, National Academy of Science, Washington, D.C. (2000).
3. Shaheen S., et al. Carsharing in Europe and North America: Past Present and Future, in *Transportation Quarterly*, Vol. 52, No. 3 (Summer 1998), pp. 35-52. (1998).
4. Massot, M. H. et al. "Praxitele: Preliminary Results from the Saint-Quentin Experiment", presented at the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., January. (1999).
5. Barth, M., Todd, M.Simulation Model Performance Analysis of a Multiple Station Shared Vehicle System, *Transportation Research, Part C: Emerging Technologies,* Vol 7, pp 237-259, Pergamon Press. (1999) .
6. Barth, M., and M. Todd (2001a)"User Behavior Evaluation of an Intelligent Shared Electric Vehicle System". *Transportation Research Record* No. 1760, pp. 145-152, Transportation Research Board, National Academy of Science, Washington, D.C. (2001).
7. Barth, M. and M. Todd (2001b)"Performance Evaluation of a Multi-Station Shared Vehicle System". *Proceedings of the IEEE Intelligent Transportation Systems Conference*, Oakland, CA, September. (2001).
8. Barth, M., M. Todd, and H. Murakami (2000a)"Using intelligent transportation system technology in a shared electric vehicle program". *Transportation Research Record* No. 1731, pp. 88-95, Transportation Research Board, National Academy of Science, Washington, D.C. (2000).
9. Barth, M. and M. Todd (2000b) "Intelligent transportation system architecture for a multi-station shared vehicle system". *Proceedings of the IEEE Intelligent Transportation Systems Conference*, Dearborn, MI, October. (2000).
10. Barth, M., L. Xue, Y. Chen, and M. Todd. "A Hybrid Communication Architecture for Intelligent Shared Vehicle Systems". *Proceedings of the IEEE Intelligent Vehicle Symposium*, Paris, France, June. (2002).

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